Analysis and Optimization of an Olive Oil Supply Chain: A Case from Turkey

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Abstract[1] The aim of this study is to determine potential improvement areas for food supply chain operations. For this purpose, a model is developed to optimize the distribution network of an olives and olive oil company in Turkey. The current distribution system of the company is analyzed and a mathematical programming model is developed to provide a distribution design to maximize the profit. An integer programming model is used and the problem is solved by using CPLEX solver/GAMS Software. Production volumes for each product type proposed by the results are different than the real production volumes. Based on the optimal results proposed by the solution, required changes in the production volumes are given. Similarly, distribution of optimal quantities of each product to each province is different than the real data. Results also suggest that, production and distribution network decisions for four different product groups must be reconsidered and production and distribution systems of the company have to be redesigned. Although this paper focuses on a single case, the model proposed in this study and findings of this study provide guidance for food supply chain members with similar problems.

Keywords Supply chain, food supply chain, olive-oil industry, distribution network optimization, Turkey.

1 Introduction

As effective supply chain management is the main source of sustainable competitive advantage for companies (Li *et al.*, 2006), the concepts of supply chain and supply chain management have received attention from many practitioners and academicians, especially in recent years (e.g. Asgari *et al.*, 2016; Thangavelu and Yee, 2017; Kwak *et al.*, 2018). However, as (Christopher and Towill, 2002) mentioned, more emphasis should be given on the industry and market specific supply chain strategies, models and practices. Correspondingly, research on food supply chain has been growing (Soysal *et al.*, 2012).

Meanwhile, the food industry has become one of the leading sectors that affects the social and economic environment by generating 7% of EU GDP (EESC, 2015). As the actors of this industry; food suppliers/growers, wholesalers, processors/producers, retailers, and consumers,

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which are also members of a food supply chain (Van der Vorst, 2000), have been affected by developments in the industry. Accordingly, supply chain practices in the food industry have become more critical for food companies' competitiveness. Therefore, the food supply chain network should be designed and managed according to the requirements and constraints of the industry due to the special characteristics of the food product (Ahumada and Villalobos, 2009). Since the quality of the food products decreases as they move downstream in the supply chain, a distribution network's performance is crucial for the whole chain's success (Musavi and Bozorgi-Amiri, 2017). For these reasons, there has been an increasing number of academic works on food supply chain in the last decades (e.g; Dellino *et al.*, 2018; Kuznietsov *et al.*, 2017; Sitek *et al.*, 2017; Zhong *et al.*, 2017). On the other hand, more specifically, the supply chain of agricultural products, has received the attention of academia (e.g. Esteso *et al.*, 2018; Moon *et al.*, 2018) in line with the increasing awareness on environmental sustainability and public health (Ahumada and Villalobos, 2009). Olive and olive-oil is one of the critical agricultural products with its positive potential impacts on public health (Taris, 2016). Moreover, although there are several studies related to perishable products (Dellino *et al.*, 2018; Bourlakis *et al.*, 2014; Rong *et al.*, 2011; Validi *et al.*, 2014; Thangam and Uthayakumar, 2010) or fresh agricultural products (Esteso *et al.*, 2018; Soto-Silva *et al.*, 2016), studies related to manufactured agricultural products such as olive oil are very limited. The work of Jerić and Šorić (2010) is one of the few examples which concentrates on supply chain management in the olive oil industry, and proposes a decision support system to maximize olive oil producers' profit by optimizing harvesting and storage of olives and production of olive oil. Thus, to the best of our knowledge, academic work devoted to olive oil supply chains are few and far between (e.g. Kazaz, 2004; Rinaldi *et al.*, 2014), and olive oil supply chains are one of the areas that are relatively unexplored. With this study, similar to the work of Kazaz (2004) we aim to contribute to the current knowledge on olive oil supply chain practices in Turkey by specifically focusing on the production planning and distribution activities of the focal company. Our study adopts a deterministic approach and uses the data provided by a leader cooperative in Turkey. The work of Rinaldi (2014) also contributed to the olive oil supply chain literature by analyzing the carbon footprint and energy footprint performance of olive oil supply chain members in Italy.

Our study addresses the research gap regarding potential improvement areas of production and distribution operations in food supply chains, particularly in olive oil supply chains. To address this gap, this article aims to examine the food supply chain by applying a mathematical model to the olive oil industry. A model is implemented and tested in the olive oil industry, based on the data gathered from Taris Olive and Olive Oil Agricultural Sales Cooperatives Union (hereafter Taris). The remainder of this paper is organized as follows. In the next section, a literature review on food supply chains is provided. In Section 2, methodology and results of the analysis are presented. In the final section, the conclusions of the study are discussed.

2 Background

2.1 Food Supply Chains

The food supply chain concept has been in the line of interest of various researchers (e.g. Aidonis *et al.*, 2015; Hill and Scudder 2002; Stank *et al.*, 2005; Van der Vorst 2000). Also, especially in recent years, emphasis by academics and practitioners has been placed on food supply chain management (Soysal *et al.*, 2012). One of the definitions of food supply chains proposed in the literature very recently by Sitek et al. (2017, p.2115) is *"the set of processes, operations and facilities that assist in changing the food from its raw material state to our plates is known as the food supply chain."*

As mentioned above, the generic food supply chain has six main members, which are the following: consumers, intermediaries-retailers, caterers, wholesalers-, food processors/manufacturers and primary producers/suppliers (e.g. agricultural producers, farmers and fishers) (Sitek *et al.,* 2017; Van der Vorst, 2000). It should also be noted that the food manufacturers may sometimes take food supplier roles, and agriculture organizations or cooperatives might be involved in the system either as a supplier, processor or a manufacturer. Also, in the majority of food supply chains, logistics activities are outsourced to third party logistics firms (Sitek et al., 2017).

Besides the members of it, types of a food supply chain should also be considered. Van der Vorst (2000, p.4) divided food supply chains into two as: *"supply chains for fresh agricultural products such as fresh vegetables, flowers, fruits"* and "*supply chains for processed food products such as snacks, desserts, and canned food products"*. Smith (2008) also defined four different types of supply chains as local, conserved, manufactured and commodity-based each showing different levels of typical features of food supply chains such as complexity of supply chain, seasonality, transportation distance, number of processing steps etc. Among the four different types of food supply chains manufactured food supply chains (e.g. olive oil) are assumed to be the most complex since they may involve many different transactions.

The food supply chain concept becomes critical for companies performing in the food industry since the food industry has some distinctive characteristics such as perishable nature of products and small contribution margins in the sector (Stank *et al.,* 2001). Bourlakis and Weightman (2004, p.2) state that the difference of food supply chains is to *"guarantee the provision of safe and healthy products that are fully traceable from farm to fork"*. There are many other characteristics of the food industry, which affect the nature of the food supply chain including seasonality of production, variability both in quality and quantity of the materials, inevitable need for waste management and materials recycling (Sitek *et al.*, 2017; Van der Vorst, 2000).

With regard to such characteristics of the food industry; velocity, flexibility, quality, cost, service and shelf life are the major drivers of food supply chain performance (Ryder and Fearne, 2003) and food quality and waste issues are the additional characteristics for food supply chain management (Sitek, *et al.* 2017). Thus, the aim of a food supply chain is not only improving operational performance but also maintaining the quality of food products (Van der Vorst *et al.*, 2011). For supply chain performance, balancing demand and supply in the food industry, especially in agri-food industry is a complex task. Taylor and Fearne (2006) proposed a process for synchronization demand and supply by reducing the variability of final demand and linking it to decisions in production levels. In this context, they suggested three factors affect demand in food supply chains: "demand variability, miss-alignment of demand and activity along the chain and poorly managed daily demand". Similarly, Taylor (2006) proposed that there are some operational features of demand management, which can be potential problems along the food chain: “complexity of procedures for handling demand information; data availability, accuracy and consistency: forecast proliferation, problems in sharing consumer demand data, timeliness of order transmission, lack of ‘on shelf availability’ data. Accordingly, a variety of aims for food supply chain entities include; decreasing lead-time, minimizing food waste and being agile and lean (Wang et al., 2002). These aims could slightly be different for a product specific food supply chain, such as olive oil supply chain, which is situated as the the main focus of this work.

2.2 Olive Oil and Olive Oil Industry in Turkey

In general, olive production can be separated into two categories “for culinary” and “for olive oil”. Olive oil is a vegetable oil that is obtained after the compression of the olive and the only raw material needed for olive oil is “olive”. Approximately 30% of an olive’s weight is olive oil (Tunalioglu, 2002). Olives are cultivated in mainly 33 different countries close to the Aegean and Mediterranean Regions including Turkey. Olives are compressed by a number of physical processes. No other raw material is included in these processes. Olive pressing plants have adopted more recent technologies and increased their capacity in Turkey. Therefore, the amount and the quality of olive oil has improved (Tunalioglu, 1995).

Olive trees are cultivated in different regions of Turkey which include: the Aegean, Mediterranean, Marmara, Southeast Anatolian and Black Sea areas. The Aegean region is the dominant region in olive production, which accounts for 76% of the total olive oil production in Turkey. Olive production in the Aegean Region and the Mediterranean Region accounts for 90% of Turkey’s total production. It should be noted that 70% of total olive production is targeted for olive oil production (Olivecenter, 2006).

Taris is chosen from various olive and olive oil manufacturers in Turkey as a research unit since it represents enough volume, contains a significant number of cooperatives, manufacturers and processing plants and produces many types of packaging modes and product types. There are 33 cooperatives and 27,000 producers that belong to Taris. Production continues with 28 modern olive pressing facilities, 14 pickling works, independent olive producing facilities, an R&D department, and an internationally accredited laboratory (Ta-Ze, 2016).

There are 5 different types of olive oil produced by Taris. Related information on the website of Taris is as follows: *“The packaging depends on the quality of olive oil. Packaging of Extra Virgin Organic and Extra Virgin Special is special glass in 500 ml, Virgin Olive Oil is in 700 ml ceramic glass; Riviera Olive Oil is in 1,000 ml, 2,000 ml, 5,000 ml and 18,000 ml tin cans and Refined is in 1,000, 2,000 and 5,000 ml bottle and tin cans”* (Ta-Ze, 2016).

3 Methodology and Analysis

In order to examine olive oil supply chain operations, and conduct and optimization analysis, a mathematical model is developed. Then the application of the model in the olive oil industry is implemented and tested. Details about the methodology and analysis are presented below.

3.1 Data Collection

Data is collected through observation and face to face interviews with Taris managers and workers. Also, information on the Taris website (Taris 2016; Ta-Ze, 2016) is used to support data collection. Face to face interviews are conducted by a semi-structured questionnaire. Questions are mainly about raw materials, suppliers, production, transportation, warehouse and distribution centers, inventory management and distribution. After these interviews, interviewees also directed us to key personnel who might be more knowledgeable in the relevant field. They also provided us supporting documents (e.g. reports). Then we could check the accuracy of the provided data.

Although the results and their implications still allow us to make correct interpretations, the production and distribution data provided by Taris and used in the analysis has been adjusted such as through multiplication by a set factor, due to confidentiality reasons.

3.2 Model

Based on the data gathered, a distribution network model for Taris is illustrated in Figure 1.

<<Insert Figure 1 here >>

As shown in the network model, there are 4 suppliers, 1 manufacturer (which is the focal company) and 5 demand points. The manufacturing facility basically acts as an olive oil bottling company, which is located in Izmir. It has 2 main divisions: a plant and finished goods warehouse. Raw materials warehouses are excluded from the model since they may not be used in all operations and they are located within the manufacturing facility.

In the production process, four groups of materials are needed: olive oil, glass, tin (cans) and other packaging materials. Each group of materials is provided by different suppliers in Turkey. Therefore, there are 4 suppliers in the model. Olive oil is provided by a single supplier in Balıkesir. Glass (bottles) is provided by a supplier in Istanbul, tin (cans) is provided by a supplier in Kocaeli, and other supporting packaging materials are provided by a supplier in Istanbul.

Taris sells finished goods to five main distribution regions in Turkey. In Figure 1, distribution regions are shown as demand points. The five regions are determined based on their distance from Izmir. For example; Denizli is 236 kilometers to Izmir and accepted as part of the second region. Similarly, Istanbul (600 km to Izmir) is in the third region, Adana (939 km to Izmir) is in the fourth region, Erzurum (1466 km to Izmir) is in the fifth region.

In this article, we utilized optimization techniques, which are widely used for different types of problems including network design, manufacturing plants and design structures. For this model, we used a minimum – cost network flow minimization formulation. The notation used in the model and the decision variables are as follows:

Notation:

i**:** product types, $i = \{1, \dots, I\}$

k**:** sales regions, $k = \{1, \dots, K\}$

p_i: sales price of product *i*

oil_i: amount of oil required to produce product *i*

oc**:** unit cost of oil

t**:** unit transportation cost of oil from Kuzey Ege (Balikesir) to the factory

toil**:** total amount of oil available for production

pc_i: packaging cost of product *i*

tc_i: unit transportation cost of packaging material for product *i* from suppliers to the factory

c_{ik}: cost of transportation for product *i* from factory to sales region *k*

d_{ik}: demand of sales region *k* for product *i*

Decision Variables:

X_i: number of product *i* produced

Y_{ik}: number of product *i* shipped to sales region *k*

In order to optimize distribution and production system of Taris by minimizing cost and maximizing profit, we propose the following mathematical model.

Maximize

$$\sum_{i=1}^{I}\sum_{k=1}^{K}(p_i - c_{ik})Y_{ik} - \sum_{i=1}^{I}(oc * oil_i - pc_i)X_i - t * toil$$

Subject to:

$$X_i \geq \sum_{k=1}^{K} Y_{ik} \qquad \forall i \qquad (1)$$

$$\sum_{i=1}^{I} oil_i X_i \leq toil \qquad (2)$$

$$Y_{ik} \leq d_{ik} \qquad \forall i, k \qquad (3)$$

$$X_i \in Z \qquad \forall\, i \qquad (4)$$

$$Y_{ik} \in Z \qquad \forall\, i, k \qquad (5)$$

In the model, the objective function aims to maximize the total profit. Constraint set 1 shows that the amount of product *i* shipped to customer region k must be less than or equal to the amount produced. Constraint set 2 limits the number of products produced by the total amount of available olive oil. Constraint set 3 states that the demand of each region may not be fully met. Constraint sets 4 and 5 state that decision variables are positive integers.

Table 1 demonstrates the different product types which are represented by (*i*) in the model.

<<Insert Table 1 here >>

In order to solve the problem, we needed the demand data. Since the demand data is not available, we made some assumptions and calculations in order to generate demand for different product types. The company provided the production percentages of each product type thus, we were able to calculate the actual production volumes of different product types. After calculating the production volumes, we separated the total production volume to different regions proportionally with their population. We assumed that all people living in a region have a demand for olive oil and the total demand of a region is proportional to its population. By making this assumption, we generated demand of products with respect to the actual production volumes of different product types gathered from the company and the population of the regions. In other words, we generate demand data by using the actual production data and the population of the regions.

Information on regions are gathered from the company. The company divides the country in five regions. The regions are defined with respect to the distances of the provinces from Izmir where the company operates.

The distances used for the regions are as follows:
Region 1: Izmir
Region 2: Provinces within 300 km distance to Izmir
Region 3: Provinces within 300 - 600 km distance to Izmir
Region 4: Provinces within 600 - 900 km distance to Izmir
Region 5: Provinces more than 900 km distance to Izmir

In order to find the provinces in different regions, all provinces in Turkey are listed. Their distances to Izmir and population data are also included in the list. Provinces are sorted in ascending order based on “their distances from Izmir”. Then, provinces falling in each of five regions are defined. In the analysis, we used population data and assumed that the whole population is in the center of the provinces. The distances used in the model are calculated according to these centers. From each region, we selected three densely populated provinces. We assumed that Taris delivers final products to these selected provinces. These provinces are represented with *k* in the model (See Appendix I).

After defining the representative provinces for each region, we made some calculations to find the representative demand of each province. First, we calculated *“production volumes of each product per year”* using the total capacity and the production percentages. We assume that all these products are consumed in the thirteen representative provinces (k). Therefore, we calculated the total population of the representative provinces. Dividing total production volume by the total population, we found *“available product volume per person”*. Then, we multiplied *“available product volume per person”* by the *“population of each province”* and found *“available production volume for each province”* and accepted it as the *“representative demand of the province according to the product”*. Production volumes of each product per year and available product per person with respect to different product types (*i*) are included in Appendix II. Appendix III presents the representative demand of the provinces (*k*) for each product type (*i*).

In order to calculate transportation costs, we added the cost of transportation from the manufacturing plant to each of 13 representative provinces. Distance based unit costs were provided by a third party logistics company in Turkey, which is located in Izmir. The transportation costs used in the analysis is for 80 m^3 trucks since the company uses its own trucks for distribution. The transportation costs for different provinces is given in Appendix IV. We calculated the volume of each final product. In the calculation 1l=0.001 m3 was used. With respect to product volumes and unit transportation costs for each region, we calculated the cost of transportation for product *i* from factory to sales region *k* (c_{ik}) and presented them in Appendix V.

4 Results

We modelled the problem using an Integer Programming Model and then solved the problem exactly using CPLEX solver on GAMS Software. It should also be noted that, earlier we mathematically modelled the multiple tour multiple traveling salesman problem using evolutionary programming (Kota & Jarmai 2015), which has several similarities to the supply chain problem.

For this model, we conducted computational experiments on an HP Laptop with AMD Triple Core Processor 1.80 GHz, 4GB RAM and Windows 7 Professional. We solved the mathematical models using GAMS 22.5 and the solver CPLEX 11.2. A Mixed Integer Programming Method is used for the analysis and the solution. We selected CPLEX solver, since it is one of the most commonly used solvers for these types of problems.

Based on our solution, production volumes for each product type proposed by the results are different than the real production volumes. In Table 2, the "optimal column" shows production volumes provided by the model. The "real column" shows the real production data of the company.

<<Insert Table 2 here >>

According to Table 2, there is a gap between the real production data and the proposed solution. Direction of the relative gap represents the need to increase or decrease in the real production volume to reach the optimal values. The size of the relative gap represents the need for percentage change in the real production volume.

Results show that, the production of olive oil in 18 liter tin cans (i=6) is not optimal. Also, optimal production levels for 5 liter tin cans (i=5) is low although the real production is high. Therefore, there is a high (negative) relative gap. On the other hand, according to the results, the production of a 250 ml glass bottle (i=7), has to be increased, since the relative gap is positive and it has the highest value. A lower, but still positive relative gap is found for 500 ml of the glass bottle (i=8).

Since the sales price of glass bottled olive oils is higher than the tin cans, it is logical to increase the production volume of both 250 ml glass bottles and 500 ml glass bottles. Also, there is increasing customer awareness about healthy foods and packaging. Therefore, it can be said that the demand for glass bottled foods would increase. According to the results, distribution of optimal quantities of each product to each province is given in Table 3.

<<Insert Table 3 here >>

Results show that, distribution of olive oil in 18 liter tin cans (*i*=6) to any of the provinces is not optimal. It is logical since it is also not optimal to market the olive oil in eighteen liter tin cans. Also, distribution of five liter tin cans (*i*=5) to the provinces in; Ankara, Kayseri, Mersin, Adana, Gaziantep, Sanliurfa and Diyarbakir is not optimal according to the results. These provinces are mainly located mainly in the fourth and fifth regions which are relatively far away from the production facility.

We also considered potential demand changes by time. Therefore, we compared optimal production quantities with respect to given demand changes. Based on these changes we solved the problem again. Table 4 presents the results regarding optimal production quantities for different demand levels.

<<Insert Table 4 here >>

Although initial results revealed that the production of olive oil in eighteen liter tin cans (*i* =6) is not optimal and the optimal production level for five-liter tin cans (*i* =5) is lower than the current production volumes, new results presented in Table four provide an alternative view. These results might provide guidance for the managers of Taris, while they are making their production plans for longer time periods. For instance, according to the new results, it is still not recommended to produce eighteen-liter tin cans (*i* =6) until the demand would decrease to 20%. To provide another example, their current production levels for one-liter glass bottles (*i* =10) are so close to optimal if demand would decrease by 20%.

We also obtained the shadow prices of the constraints. For the first constraint, which was limiting the number of product *i* shipped to all regions with the total number of product *i* produced, increasing the amount of production had a positive effect on the objective function. If the company were able to produce finished goods in higher quantities and since there was still some demand that is unmet, the profit would increase. The results for the second constraint, which limited the total number of product *i* produced with the total amount of oil available, were similar. If the total amount of available oil increases, so does the objective value and the profit of the company. The shadow prices of these two constraints both show that the company could produce more in order to increase its profit since the demand is higher than their production. In that case, the company should increase its investments and production capacity. The third constraint, which was limiting the number of product *i* shipped to sales region *k* with the demand for that product in the given region, also increases the objective value. If the demand for a product type in a specific region increases the objective value also increases. In this case the company may enhance their promotion efforts in order to increase the demand. For all constraints, it seems like increasing them would improve the objective value. However, since we do not have all information regarding the cost of investment in order to increase the production or demand, it would be more realistic for the company to make a comparison of cost and profits that they will incur doing these changes.

In order to compare the results, we generated a second set of demand data using per capita olive oil consumption in Turkey, the market share of the focal company and the generated consumption percentages. The alternative demand data is presented in Appendix VI. After solving the model with the alternative demand data, the results are as follows. Table 5 presents the optimal production quantities of each product and Table 6 presents the distribution of optimal quantities of each product to each province.

<<Insert Table 5 here >>

<<Insert Table 6 here >>

5 Conclusions and recommendations for further research

In this study, first, we formulated a generic model for a food supply chain. Then, we proposed a distributed network model for an olive oil supply chain of a company which operates in Turkey. For the analysis, we used a mathematical programming model. The proposed model aims to optimize distribution and the production system of Taris by minimizing cost and maximizing profit. We modelled the problem using an integer programming model and solved the problem exactly using CPLEX solver on GAMS Software and with the Solver add-in of Microsoft Excel.

When we compared the initial results of our solution and the current data, we realized that the production volume for each product type proposed by the results are different than the current production volume. The results proposed by the mathematical model are better in terms of cost minimization and profit maximization. Based on the optimal results proposed by the solution, required changes in the production volumes are presented. Similarly, distribution of optimal quantities of each product to each province is different than the current data. Considering these results, a number of conclusions have been reached.

Based on the comparisons between optimal results and current data, production and distribution network decisions for eighteen lt. and five lt. tin cans as well as 250 ml. and 500 ml. glass bottles could be reconsidered. Taris could consider decreasing the production volumes of both eighteen lt. and five lt. tin cans if they expect the current demand level to remain steady. Similarly, they could consider increasing the production volume of 250 ml. and 500 ml. glass bottles. It should also be noted that, the unit price of a glass bottle of olive oil is higher than a tin can. Therefore, it would be logical to increase the production volumes of both 250 ml glass bottles and 500 ml glass bottles. Since, there is increasing customer awareness about healthy foods and packaging, an increase in demand for glass bottled olive oil could be expected as well.

On the other hand, results of further analysis which consider different demand levels provided alternative optimal production levels for each product type. We believe these results might provide guidance for the managers of Taris while they are making their production plans for longer time periods. As an example, according to the results for different demand levels, continuing to produce 18 lt. tin cans would not be recommended until the demand would decrease by 20%. Distribution decisions would also be affected by production decisions accordingly. Therefore, we believe that our results would provide an alternative view for Taris managers in their future production and distribution decisions.

Moreover, a further in-depth analysis which considers shadow prices of the constraints provided interesting results for Taris as well. It was revealed that if Taris were able to produce higher amounts of finished goods, and/or to reach olive oil in higher quantities, they would be able to respond to their unmet demand. Thus, their profit would increase accordingly. We believe that, this result could lead Taris managers to re-think a trade-off between more profit by increasing production levels and tying up capital to an extended production capacity. It was also found that as demand for a product type in a specific region increases, the objective value also increases. This result could be meaningful for Taris if they reconsidered their marketing strategies. If they would conduct an effective promotion campaign in order to increase the demand in targeted regions.

The findings of this study address a research gap concerning potential improvement areas of the production and distribution operations in food supply chains, particularly in olive oil supply chains. Although this paper focuses on a single case, the model proposed in this study and findings of this research provide a guide for food supply chain members with similar problems.

As a reference for further research, problems of other companies operating in the same sector can be further investigated. We also invite other scholars to use and modify this model for other companies operating in similar food industries. Obviously, the solution may also be carried out by using real demand data. This was one of the limitations of our study. Alternatively, other members of the supply chain can be included in the model and the problem can be tested again. The same problem can also be applied to the other product categories.

References

Ahumada, O. and Villalobos, J.,R. (2009) 'Application of planning models in the agri-food supply chain: a review', *European Journal of Operational Research,* Vol.196, No.1, pp.1-20.

Aidonis, D., Folinas, D., Achillas, C., Triantafyllou, D. and Malindretos, G. (2015) 'Multi-criteria evaluation of sustainable supply chains in the agrifood sector', *International Journal of Sustainable Agricultural Management and Informatics,* Vol. 1, No.2, pp. 106-119.

Asgari, N., Nikbakhsh, E., Hill, A. and Farahani, R.,Z. (2016) 'Supply chain management 1982–2015: a review', *IMA Journal of Applied Mathematics,* Vol.27, No.3, pp.353–379.

Bourlakis, M., Maglaras, G., Gallear, D. and Fotopoulos, C. (2014) ‘Examining sustainability performance in the supply chain: The case of the Greek dairy sector’, *Industrial Marketing Management*, Vol.43, No.1, pp.56–66.

Bourlakis, M. and Weightman, P. (2004) Food Supply Chain Management. Blackwell, Oxford.

Christopher, M. and Towill, D.R. (2002) ‘Developing market specific supply chain strategies’, *International Journal of Logistics Management*, Vol.13, No.1, pp.1-14.

Dellino, G., Laudadio T., Mari R, Mastronardi, N, and Meloni, C. (2018) ‘A reliable decision support system for fresh food supply chain management’, *International Journal of Production Research*, Vol.56, No.4, pp.1458-1485.

EESC (2015) EESC report on food and drinks sector. https://www.eesc.europa.eu/en/our-work/opinions-information-reports/opinions/food-and-drinks-sector. Accessed 12 March 2017

Esteso, A., Alemany, M. and Ortiz, A. (2018) ‘Conceptual framework for designing agri-food supply chains under uncertainty by mathematica programming models’, *International Journal of Production Research*, Vol.56, No.13, pp.4418–4446.

Hill, A.,C. and Scudder, G., D. (2002) ‘The use of electronic data interchange for supply chain coordination in the food industry’, *Journal of Operations Management*, Vol.20, No.4,pp.375-87.

Jerić, S.,V. and Šorić, K. (2010) ‘Single criterion supply chain management in olive oil industry’, *Croatian Operational Research Review*, Vol.1, pp.138-147.

Kazaz, B. (2004) ‘Production planning under yield and demand uncertainty with yield-dependent cost and price’, *Manufacturing & Service Operations Management*, Vol.6, No.3, pp.209–224.

Kota, L. and Jármai, K. (2015) ‘Mathematical modeling of multiple tour multiple traveling salesman problem using evolutionary programming’ *Applied Mathematical Modelling*, Vol.39. No.12, pp.3410-3433.

Kuznietsov, K.A., Gromov, V., A. and Skorohod, V.,A. (2017) ‘Cluster-based supply chain logistics: a case study of a Ukrainian food distributor’, *IMA Journal of Applied Mathematics*, Vol.28, No.1, pp.553-578.

Kwak, D., Seo, Y. and Mason, R. (2018) ‘Investigating the relationship between supply chain innovation, risk management capabilities and competitive advantage in global supply chains’, *International Journal of Operations & Production Management*, Vol.38, No.1, pp. 2-21.

Li, S., Ragu-Nathan, B, Ragu-Nathan, T, and Rao, S., S. (2006) 'The impact of supply chain management practices on competitive advantage and organizational performance', *Omega* Vol.34, No.2, pp.107-124.

Moon, I., Jeong, Y., J., and Saha, S. (2018) 'Investment and coordination decisions in a supply chain of fresh agricultural products', *Operational Research:An International Journal,*pp.1-25.

Musavi, M., Bozorgi-Amiri A. (2017) 'A multi-objective sustainable hub location-scheduling problem for perishable food supply chain', *Computers & Industrial Engineering,* Vol.113, pp.766–778.

Olivecenter (2006) http://www.olivecenter.net/. Accessed 25 November 2006

Rinaldi, S., Barbanera, M. and Lascaro, E. (2014) 'Assessment of carbon footprint and energy performance of the extra virgin olive oil chain in Umbria, Italy', *Science of the Total Environment,* Vol. 482–483, pp.71-79.

Rong, A., Akkerman, R. and Grunow, M. (2011) 'An optimization approach for managing fresh food quality throughout the supply chain', *International Journal of Production Econonmics,* Vol.131, No.1, pp.421–429.

Sitek, P., Wikarek, J. and Nielsen, P. (2017) 'A constraint-driven approach to food supply chain management', *Industrial Management & Data Systems,* Vol.117, No.9, pp.2115-2138.

Smith, B.G. (2008) 'Developing Sustainable Food Supply Chains', *Philosophical Transactions of the Royal Society B,* Vol.363, No.1492, pp.849-861.

Soto-Silva, W.E., Nadal-Roig, E., González-Araya, M.C. and Pla-Aragones, L.M. (2016) 'Operational research models applied to the fresh fruit supply chain', *European Journal of Operational Research,* Vol.251, No.2, pp.345–355.

Soysal, M., Bloemhof-Ruwaard, J., Meuwissen, M, and van der Vorst, J. (2012) 'A review on quantitative models for sustainable food logistics management', *International Journal on Food System Dynamics,* Vol.3, No.2, pp.136-155.

Stank, T.P., Davis, B.R. and Fugate, B.S. (2005) 'A strategic framework for differentiating SCM from logistics', Journal of Business Logistics, Vol.26, No.2, pp.27-46.

Taris (2016) http://www.tariszeytinyagi.com/. Accessed 25 November 2016

Taylor, D.H. (2006) 'Strategic considerations in the development of lean agri-food supply chains: a case study of the UK pork sector', *Supply Chain Management:An International Journal,* Vol.11, No.3, pp.271-280.

Taylor, D.H. and Fearne, A. (2006) ‘Towards a framework for improvement in the management of demand in agri-food supply chains’, *Supply Chain Management:An International Journal,* Vol.11, No.5, pp.379-384.

Ta-Ze (2016) http://www.ta-ze.ca/ca/en/default.aspx. Accessed 25 November 2016

Thangam, A. and Uthayakumar, R. (2010) ‘Optimal pricing and lot-sizing policy for a two-warehouse supply chain system with perishable items under partial trade credit financing’, *Operational Research:An International Journal*, Vol.10, No.2, pp.133–161.

Thangavelu, I. and Yee, C., L. (2017). ‘Creating sustainable supply chain for palm oil’, *International Journal of Sustainable Agricultural Management and Informatics,* Vol. 3, No.2, pp. 103-124.

Tunalioglu, R. (1995). ‘Türkiye Zeytinciliğinin Genel Durumu’, *Zeytin Yetiştiriciliği Kursu Zeytincilik Araştırma Enstitusu Dergisi,* Vol. 5, pp.14-21.

Tunalioglu, R. (2002). ‘Zeytinyağı’, *Tarimsal Ekonomi Araştırma Enstitüsü-Bakış*, Vol.1, No.4, ISSN: 1303-83462002.

Validi, S., Bhattacharya, A. and Byrne, P. (2014) ‘A case analysis of a sustainable food supply chain distribution system: a multi-objective approach’, *International Journal of Production Econonmics,* Vol.152, pp.71–87.

Van der Vorst, J., G, .A., J. (2000) ‘Effective food supply chains: generating, modeling and evaluating supply chain scenarios’, PhD Dissertation, Wageningen University.

Van der Vorst, J., G., Kooten, O.,V. and Luning, P., A. (2011) ‘Towards a diagnostic instrument to identify improvement opportunities for quality controlled logistics in agrifood supply chain networks’, *International Journal on Food System Dynamics,* Vol.2, No.1, pp.94-105.

Wang, Y., Cohen, M.A. and Zheng, Y. (2002) ‘Differentiating customer service on the basis of the delivery lead times’, IIE Transactions, Vol.34, No.11, pp.979-998.

Zhong, R., Xu, X. and Wang, L. (2017) ‘Food supply chain management: systems, implementations, and future research’, *Industrial Management & Data Systems,* Vol.117, No.9, pp.2085-2114.

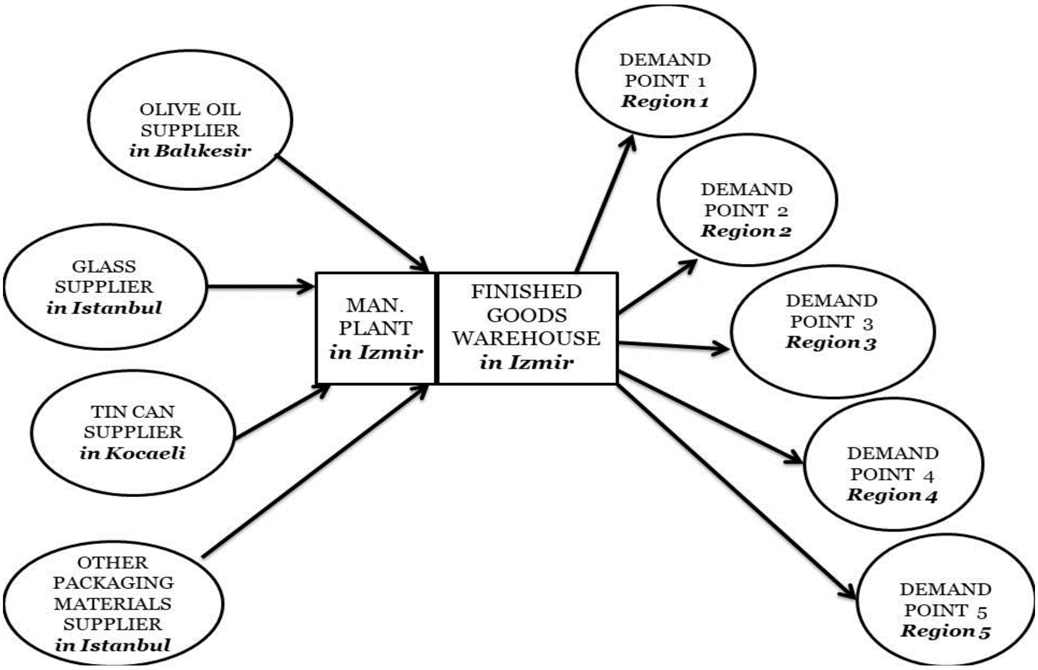

Fig. 1. Olive Oil Network Model of Taris in Turkey

Table 1. Final Products of Taris.

i	Type of the final product
1	1 liter tin cans
2	1.5 liter tin cans
3	2 liter tin cans
4	3 liter tin cans
5	5 liter tin cans
6	18 liter tin cans
7	250 ml glass bottle
8	500 ml glass bottle
9	750 ml glass bottle
10	1 liter glass bottle

Table 2. Calculated production volumes.

i	Optimal	Current	Relative Gap
1	73,413	59,483	0.23
2	80,836	98,246	-0.18
3	63,789	103,370	-0.38
4	21,341	51,878	-0.59
5	14,219	137,371	-0.90
6	0	6,837	-1.00
7	48,879	9,901	3.94
8	51,236	20,757	1.47
9	33,028	35,680	-0.07
10	20,026	16,226	0.23

Table 3. Distribution of optimal quantities to provinces.

Demand (*i*/k)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	7,872	2,017	1,517	1,399	5,039	28,639	10,131	2,323	2,796	4,008	3,278	2,014	2,380
2	8,668	2,221	1,670	1,541	5,549	31,535	11,155	2,558	3,079	4,414	3,609	2,217	2,620
3	6,840	1,753	1,318	1,216	4,378	24,884	8,803	2,018	2,430	3,483	2,848	1,750	2,068
4	2,288	586	441	407	1,465	8,326	2,945	675	813	1,165	953	585	692
5	3,636	932	701	646	2,327	5,977	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5,241	1,343	1,010	932	3,355	19,068	6,745	1,547	1,862	2,669	2,182	1,341	1,584
8	5,494	1408	1,059	977	3,517	19,987	7,070	1,621	1,952	2,798	2,287	1,405	1,661
9	3,541	908	682	630	2,267	12,884	4,558	1,045	1,258	1,803	1,475	906	1,071
10	2,147	550	414	382	1,375	7,812	2,764	634	763	1,093	894	549	649

Table 4. Optimal production quantities with respect to demand changes.

i/change in demand	-20%	-10%	0%	+10%	+20%	Current
1	58,730	66,071	73,413	80,754	88,095	59,483
2	64,668	72,752	80,836	88,919	97,003	98,246
3	51,031	57,410	63,789	70,167	76,546	103,370
4	17,072	19,206	21,341	23,475	18,048	51,878
5	27,126	23,597	14,219	4,841	0	137,371
6	376	0	0	0	0	6,837
7	129,014	43,991	48,879	53,766	58,654	9,901
8	409,88	46,112	51,236	56,359	61,483	20,757
9	26,422	29,725	33,028	36,330	39,,633	35,680
10	16,020	18,023	20,026	22,028	24031	16,226

Table 5. Optimal production quantities for alternative demand data.

i	Production volume
1	11,569,730
2	8,475,500
3	5,011,304
4	1,121,093
5	1,062,794
6	3,731
7	121,879,500
8	16,278,350
9	6,905,960
10	3,161,493

Table 6. Distribution of optimal quantities to provinces for the alternative demand.

Demand (*i*/k)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1,240,576	317,947	239,054	220,535	794,149	4,513,485	1,596,592	366,072	440,680	631,732	516,538	317,353	375,019
2	908,794	232,915	175,121	161,555	581,760	3,306,390	1,169,596	268,169	322,824	462,780	378,394	232,479	274,723
3	537,342	137,715	103,543	95,522	343,977	1,954,968	691,547	158,560	190,876	273,628	223,733	137,458	162,435
4	120,210	30,808	23,164	21,369	76,952	437,353	154,708	35,472	42,701	61,214	50,052	30,751	36,339
5	113,959	29,206	21,959	20,258	72,950	414,610	146,663	33,627	40,481	58,031	47,449	29,152	34,449
6	400	102	77	71	256	1,457	515	118	142	204	166	102	121
7	3,317,819	850,325	639,331	589,805	2,123,888	12,070,948	4,269,955	979,030	1,178,564	1,689,517	1,381,440	848,735	1,002,958
8	1,745,461	447,345	336,344	310,289	1,117,349	6,350,368	2,246,367	515,055	620,027	888,833	726,757	446,508	527,643
9	740,498	189,782	142,691	131,637	474,027	2,694,095	953,004	218,508	263,041	377,080	308,321	189,428	223,848
10	338,994	86,881	65,323	60,262	217,005	1,233,336	436,278	100,031	120,418	172,624	141,147	86,718	102,476

Appendix I. Densely populated provinces.

k	Provinces	Region	Distance to Izmir	Population
1	Izmir	1st	0	3,606,326
2	Manisa	2nd	36	924,267
3	Balıkesir	2nd	173	694,926
4	Denizli	2nd	224	641,093
5	Bursa	3rd	322	2,308,574
6	Istanbul	3rd	565	13,120,596
7	Ankara	3rd	580	4,641,256
8	Kayseri	4th	867	1,064,164
9	Mersin	4th	889	1,281,048
10	Adana	4th	896	1,836,432
11	Gaziantep	5th	1105	1,501,566
12	Sanliurfa	5th	1242	922,539
13	Diyarbakir	5th	1422	1,090,172

Appendix II. Production and available product volumes.

i	Volume of production (per year)	Volume available (per person)
1	59,483	0.00218
2	98,246	0.00240
3	103,370	0.00190
4	51,878	0.00063
5	137,371	0.00101
6	6,837	0.00001
7	9,901	0.00145
8	20,757	0.00152
9	35,680	0.00098
10	16,226	0.00060

Appendix III. Representative demand volume.

Demand (*i*/k)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	7,872	2,017	1,517	1,399	5,039	28,639	10,131	2,323	2,796	4,008	3,278	2,014	2,380
2	8,668	2,221	1,670	1,541	5,549	31,535	11,155	2,558	3,079	4,414	3,609	2,217	2,620
3	6,840	1,753	1,318	1,216	4,378	24,884	8,803	2,018	2,430	3,483	2,848	1,750	2,068
4	2,288	586	441	407	1,465	8,326	2,945	675	813	1,165	953	585	692
5	3,636	932	701	646	2,327	13,228	4,679	1,073	1,292	1,851	1,514	930	1,099
6	50	13	10	9	32	183	65	15	18	26	21	13	15
7	5,241	1,343	1,010	932	3,355	19,068	6,745	1,547	1,862	2,669	2,182	1,341	1,584
8	5,494	1.,408	1,059	977	3,517	19,987	7,070	1,621	1,952	2,798	2,287	1,405	1,661
9	3,541	908	682	630	2,267	12,884	4,558	1,045	1,258	1,803	1,475	906	1,071
10	2,147	550	414	382	1,375	7,812	2,764	634	763	1,093	894	549	649

Appendix IV. Transportation costs based on distances to Izmir.

k	Total transportation cost (tax added) (Turkish Liras)	Calculated transportation cost (tax added) – including truck capacity constraint (per m^3)
1	0	0
2	413.00	5.1625
3	649.00	8.1125
4	885.00	11.0625
5	944.00	11.8000
6	1,298.00	16.2250
7	1,534.00	19.1750
8	2,065.00	25.8125
9	2,360.00	29.5000
10	2,360.00	29.5000
11	2,832.00	35.4000
12	3,186.00	39.8250
13	3,186.00	39.8250

Appendix V. Transportation cost of product *i* to region *k*.

(*i*/k)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.003	0.005	0.008	0.011	0.012	0.016	0.019	0.026	0.030	0.030	0.035	0.040	0.040
2	0.004	0.008	0.012	0.017	0.018	0.024	0.029	0.039	0.044	0.044	0.053	0.060	0.060
3	0.005	0.010	0.016	0.022	0.024	0.032	0.038	0.052	0.059	0.059	0.071	0.080	0.080
4	0.008	0.015	0.024	0.033	0.035	0.049	0.058	0.077	0.089	0.089	0.106	0.119	0.119
5	0.013	0.026	0.041	0.055	0.059	0.081	0.096	0.129	0.148	0.148	0.177	0.199	0.199
6	0.046	0.093	0.146	0.199	0.212	0.292	0.345	0.465	0.531	0.531	0.637	0.717	0.717
7	0.001	0.001	0.002	0.003	0.003	0.004	0.005	0.006	0.007	0.007	0.009	0.010	0.010
8	0.001	0.003	0.004	0.006	0.006	0.008	0.010	0.013	0.015	0.015	0.018	0.020	0.020
9	0.002	0.004	0.006	0.008	0.009	0.012	0.014	0.019	0.022	0.022	0.027	0.030	0.030
10	0.003	0.005	0.008	0.011	0.012	0.016	0.019	0.026	0.030	0.030	0.035	0.040	0.040

Appendix VI. Alternative demand volume.

Demand (*i*/k)	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1,240,576	317,947	239,054	220,535	794,149	4,513,485	1,596,592	366,072	440,680	631,732	516,538	317,353	375,019
2	908,794	232,915	175,121	161,555	581,760	3,306,390	1,169,596	268,169	322,824	462,780	378,394	232,479	274,723
3	537,342	137,715	103,543	95,522	343,977	1,954,968	691,547	158,560	190,876	273,628	223,733	137,458	162,435
4	120,210	30,808	23,164	21,369	76,952	437,353	154,708	35,472	42,701	61,214	50,052	30,751	36,339
5	113,959	29,206	21,959	20,258	72,950	414,610	146,663	33,627	40,481	58,031	47,449	29,152	34,449
6	400	102	77	71	256	1,457	515	118	142	204	166	102	121
7	3,317,819	850,325	639,331	589,805	2,123,888	12,070,948	4,269,955	979,030	1,178,564	1,689,517	1,381,440	848,735	1,002,958
8	1,745,461	447,345	336,344	310,289	1,117,349	6,350,368	2,246,367	515,055	620,027	888,833	726,757	446,508	527,643
9	740,498	189,782	142,691	131,637	474,027	2,694,095	953,004	218,508	263,041	377,080	308,321	189,428	223,848
10	338,994	86,881	65,323	60,262	217,005	1,233,336	436,278	100,031	120,418	172,624	141,147	86,718	102,476